Astron. Astrophys. 324, 91–96 (1997)

ASTRONOMY AND ASTROPHYSICS

Red giants in open clusters

VII. Melotte 71*,**

J.-C. Mermilliod[1], **J.J. Clariá**[2], **J. Andersen**[3], **and M. Mayor**[4]

[1] Institut d'Astronomie de l'Université de Lausanne, CH-1290 Chavannes-des-Bois, Switzerland
[2] Observatorio Astronómico, Laprida 854, 5000 Córdoba, Argentina
[3] Niels Bohr Institute for Astronomy, Physics, and Geophysics, Astronomical Observatory, Juliane Maries Vej 30, DK-2100 Copenhagen Ø, Denmark
[4] Observatoire de Genève, CH-1290 Sauverny, Switzerland

Received 7 November 1996 / Accepted 6 December 1996

Abstract. New CORAVEL radial-velocity observations and UBV photometry of 24 red giants in the field of the intermediate-age open cluster Mel 71 are analysed for membership and duplicity. The membership of 16 stars is confirmed, one star is a possible member, and 8 spectroscopic binaries have been discovered, all amongst the cluster stars. Four of their orbits have been determined, with periods ranging from 74 to 1627 days. The mean cluster velocity is +50.14 $\pm$ 0.14 (s.e.) km s^{-1}, and the binary frequency is unusually high (8/16 = 50%). The best isochrone fit to the observed colour-magnitude digram is obtained for $logt$ = 9.00 and Z = 0.008. However, some discrepancies appear between the observed and predicted locations of the red giant clump.

Key words: cluster: open – individual: Mel 71 – binaries: spectroscopic – HR diagram

1. Introduction

Within a series of papers devoted to the study of red giants in open clusters by means of CORAVEL radial-velocity data and new photoelectric photometry, we discuss in the following the membership and duplicity of 24 red giants in the field of the intermediate-age cluster Mel 71 = C0735-119 (α = $7^{\rm h}$35.2, $\delta = -11°57'$, B1950). Knowledge of the detailed distribution of the red giant stars in the colour-magnitude diagram is important for comparisons with theoretical isochrones in order to better delineate the precise evolutionary path of the red giants. The determination of the membership and binary character of the individual red giants enables us to define the single-star locus. Our long-term goal is to study the general distribution of orbital elements of cluster red-giant spectroscopic binaries, and a large effort is being made to monitor more than 150 stars with variable radial velocities. One of the main interests of this programme is the possibility of determining the distribution of orbital elements for spectroscopic binaries with different masses of the primary by combining data for red giants and red dwarfs in open clusters and field dwarfs. For example, any difference in the mass ratio distribution, f(M_2) or f(M_2/M_1), in function of the primary mass M_1 will be an interesting test of the various binary star-formation scenarios. Preliminary results were published by Mermilliod & Mayor (1992, 1996), and results for five clusters with ages similar to that of Mel 71 were given in Paper III of this series (Mermilliod & Mayor 1990).

Although Mel 71 is not very faint, it had not been studied before Hassan (1976) published UBV photographic photometry for 230 stars. The colour-magnitude diagram shows that the cluster is a little older than the Hyades and shows prominent red giant clump. Later, Pound & Janes (1986) also published UBV photographic photometry for 631 stars, mostly fainter than V = 14. Geisler et al. (1992) observed 16 red giants in the Washington photometric system and derived a low metallicity $[Fe/H]$ = -0.57 $\pm$ 0.18, assuming $E(B-V)$ = 0.10 (Pound & Janes 1986). The presence of numerous red giants in the field of Mel 71 makes it an interesting cluster in which to study the red giant population.

2. Observations

2.1. Radial-velocity measurements

All stars redder than $B-V$ = 0.40 and brighter than V = 12.50 in Hassan's (1976) colour-magnitude diagram were selected as red giant candidates and measured with the radial-velocity scan-

Send offprint requests to: J.-C. Mermilliod

* Based on observations collected with the Danish 1.54-m telescope at the European Southern Observatory, La Silla, Chile and at Cerro Tololo Interamerican Observatory

** Table 4 is available in electronic form at the CDS by ftp at 130.79.128.5

ner CORAVEL (Baranne et al. 1979) installed on the 1.54-m Danish telescope at ESO, La Silla, Chile. At least four observations were obtained through the period 1987 - 1996 for the non-variable stars. The radial velocities are on the standard system defined by Mayor & Maurice (1985), which corresponds to the system defined by the faint IAU standard stars ($m_v > 4.3$). Radial velocities of standard stars and asteroids obtained with different instruments show that CORAVEL data may differ from an absolute zero point by as much as 0.4 km s^{-1}. This possible offset is of no importance for this study, which is primarily concerned with radial-velocity differences between similar-type stars within the cluster.

2.2. Photometry

Most of the UBV observations were made with the ESO 1.0m telescope at La Silla (Chile) during March 1988. A dry-ice cooled RCA 31034 (Quantacon) Ga-As photomultiplier was used with pulse-counting equipment and standard UBV filters. Mean extinction coefficients for La Silla were used, and 12-18 standard stars from the lists of Cousins (1973, 1974) and Graham (1982) were observed nightly to transform to the standard UBV system.

Additional UBV observations were obtained in January and April 1993 with the 0.6m and 1.0m telescopes at Cerro Tololo Inter-American Observatory (CTIO). For these observations, a single channel pulse-counting photometer equipped with a dry-ice cooled Hamamatsu R943-02 was employed. Nearly the same standards were observed as for the La Silla observations, and mean extinction coefficients were also employed. No evidence for systematic discrepancies either in V or the $(B-V)$ and $(U-B)$ colours among the stars observed at both observatories was found. Therefore, unweighted averages of the UBV observations of each star were formed. The mean standard deviations of a single observation are: $\pm$ 0.017 in V, $\pm$0.011 in $(B-V)$ and $\pm$0.018 in $(U-B)$. The mean UBV data are given in Table 1 in column 2 to 4.

Comparison of the new UBV photoelectric data with Hassan's (1976) photographic values shows quite large systematic differences: $\Delta V = 0.89 \pm .045$, $\Delta B-V = 0.246 \pm .045$, $\Delta U-B$ = 0.34 $\pm$ 0.28. Fig. 1 shows that a constant correction would, in first approximation, be sufficient. Pound & Janes (1986) found a linear dependence of ΔV relative to their own photographic data as a function of magnitude (ΔV = -0.10 V) for 10.5 $<$ V $<$ 16.

2.3. Results

The observational data are summarized in Table 1. Successive columns contain the numbers from Hassan (1976), the V magnitudes, $B-V$ and $U-B$ colour indices, the number of measurements, the mean radial velocity and its error in [km s^{-1}], the number of radial-velocity observations, the time spanned by the observations, the probability that the scatter is merely due to random noise, and remarks on membership and duplicity (SB = spectroscopic binary, M = member, NM = non-member).

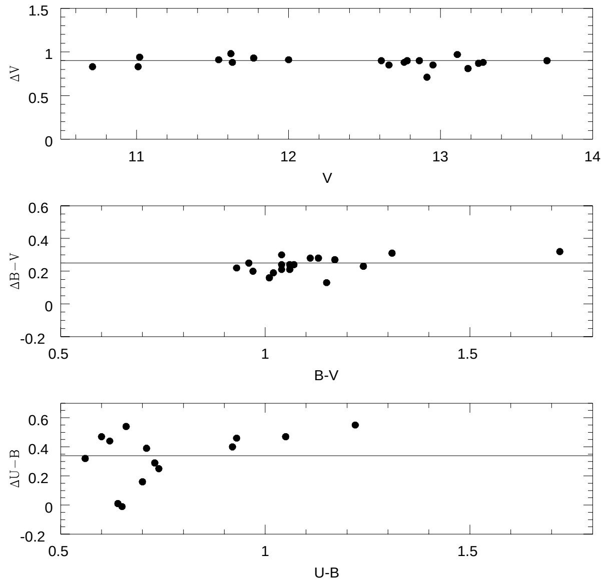

Fig. 1. Magnitude and colour differences (this paper - Hassan (1976)).

The photographic V magnitudes for stars H29 and H110 are 12.69 and 12.77 respectively (Hassan (1976) data, corrected by 0.89 mag). The individual CORAVEL observations (Table 4) are available in electronic form only at the CDS by ftp at 130.79.128.5.

3. Discussion

3.1. Mean cluster velocity

Based on the 7 constant obvious members and 4 binaries with orbits from Table 2, the mean radial velocity of Mel 71 is +50.14 $\pm$ 0.14 km s^{-1} (s.e. of the mean). To our knowledge, this is the first determination of the radial velocity of Melotte 71.

3.2. Membership

The radial velocities of the obvious members fall within an interval of only 1.3 km s^{-1} (from 49.31 to 50.65 km s^{-1}), while two stars (H127 & 160) differs by 1.2 and 2.0 km s^{-1} from the mean velocity. To assign membership probabilities to individual stars in a quantitative manner we proceed as follows.

From the observed standard deviation (0.47 km s^{-1}) of the 11 mean velocities used above and the average observational error per star (column 9) of 0.24 km s^{-1}, we estimate the intrinsic velocity dispersion of the cluster giants to be 0.40 km s^{-1}. Adding this term quadratically to the observational uncertainty of each star gives the predicted standard deviation of the velocity of that star from the cluster mean. The ratios of observed to predicted velocity differences are then our best measure of the significance of the observed velocity residuals. For a ratio less than 2.5 (numerically) the star is considered a certain cluster member, between 2.5 and 3.5 a possible member, while a ratio exceeding 3.5 indicates a probable non-member.

Table 1. Observational data for red giants in Melotte 71

No	α(2000)	δ(2000)	V	B-V	U-B	N	V_r	ϵ	n	ΔT	P(χ^2)	Remarks
3	7 37 57.9	-12 06 40	13.110	1.044	0.651	2	50.13	0.22	4	3211	.832	M
19	7 37 42.7	-12 07 07	12.783	1.040	0.712	2	49.34	0.37	4	1154	.058	M
23	7 37 42.3	-12 04 54	11.008	1.314	1.224	2	49.23	0.22	4	3214	.177	M
29	7 37 35.5	-12 04 38					43.30	2.01	3	1067	.000	M?, SB
56	7 37 29.2	-12 05 28	13.190	1.035	0.556	3	50.10	0.63	9	3213	.000	M, SB
69	7 37 42.3	-12 04 54	11.530	1.126	0.920	3	0.92	0.89	3	1446	.004	NM
83	7 37 19.4	-12 05 50	9.367	1.743	1.901	2	50.21	0.14	4	3214	.416	M
84	7 37 22.1	-12 05 26	13.276	1.052	0.641	3	50.55	0.23	4	3212	.778	M
98	7 37 12.3	-12 02 35	10.706	1.724	2.096	2	95.15	0.37	3	2148	.021	NM
107	7 37 21.3	-12 04 05	11.629	1.064	0.742	1	50.46	0.10	30	3218	.000	M, SB, orbit
110	7 37 24.8	-12 04 33				2	50.42	0.17	25	3224	.000	M, SB, orbit
114	7 37 23.3	-12 03 14	11.620	1.858	2.143	2	67.82	0.24	3	2891	.492	NM
118	7 37 25.1	-12 02 24	12.945	0.932	0.492	3	50.48	0.11	26	3224	.000	M, SB, orbit
121	7 37 30.1	-12 02 24	12.762	1.069	0.722	2	50.60	0.23	4	3215	.283	M
127	7 37 28.4	-12 03 56	12.001	1.241	1.055	3	49.05	1.75	5	3214	.000	M, SB
130	7 37 30.1	-12 04 24	12.665	1.106	0.726	3	49.60	0.21	4	2892	.758	M
145	7 37 35.1	-12 03 26	13.167	1.014	0.641	2	49.79	0.60	4	3212	.000	M, SB
151	7 37 35.7	-12 02 54	12.856	0.980	0.601	3	50.58	0.14	38	3223	.000	M, SB, orbit
160	7 37 38.1	-12 02 29	12.606	0.980	0.616	3	52.13	0.28	4	2894	.252	M?
180	7 37 49.2	-11 59 25	11.015	1.861	2.153	2	63.95	0.22	3	2890	.724	NM
185	7 37 43.1	-12 00 42	11.767	1.176	0.932	2	-7.22	0.41	3	2894	.028	NM
211	7 37 32.8	-12 01 04	12.945	1.041	0.631	2	66.46	0.27	3	2888	.367	NM
213	7 37 31.0	-12 01 07	13.255	1.006	0.656	3	50.10	0.55	4	3212	.001	M, SB
242	7 37 09.3	-12 01 20	13.699	1.146	0.840	2	43.98	0.56	3	1067	.004	NM

For the small number of observations obtained here, low-amplitude and/or long-period binaries may cause some ambiguity in these assignments which can in principle be resolved by further observation and/or improved precision. In practice, the current results are fully adequate for a discussion of the age and other principal properties of the cluster. The membership of 16 red giants is confirmed by the radial-velocity criterion discussed above, while one (H160) remains a possible member and H242, whose 8-σ velocity residual currently classifies it as a non-member, could be revealed by further observation to be a long-period, low-amplitude binary.

3.3. Spectroscopic binaries

Taking a confidence level of 99% as the criterion for certain detection of spectroscopic binaries (P(χ^2) $<$ 0.010), we detect nine binaries amongst the cluster giants, one of which (H213) is perhaps a marginal case. Four of these binaries have been observed systematically, and their orbits have been determined. Observations of three more spectroscopic binaries (H29, 56 and 127) will be continued, since first orbital cycle has not been covered during the first 9 years of observations. The overall binary frequency (8/16 = 50%) of Mel 71 is unusually high among the open clusters included in this survey (Mermilliod & Mayor 1992).

The elements of the four orbits determined up to now are presented in Table 2, and the radial-velocity curves are shown in Figs. 2 to 5. The shortest period is 74^{d} (H110), and the orbit is circular. This is expected, since this value is well below the cut-off period for circular orbits. The latter value is about 120 days, with a clear dependence on the red giant mass (Mermilliod & Mayor 1990, 1996). Correspondingly, the non-zero eccentricity of the orbit of H118 is also expected because the period (155^{d}) is longer than the cut-off period. The two other binaries have even longer periods. The eccentricity for H151 is remarkably high.

The two bottom rows of Table 2 give, first, the minimum masses of the secondaries as derived from the spectroscopic mass function $f(m)$ by assuming primary masses of 2.20 $M_\odot$ for H107 and 2.10 $M_\odot$ for the other three stars as deduced from the isochrone. Below, we give for comparison the masses deduced from the photometric separation of the combined light. In all four cases the spectroscopic mass functions are rather large, which indicates that the secondaries are relatively massive compared to the primary. The observed blue-ward location of the binaries in the colour-magnitude diagram relative to the single stars and the isochrone is therefore naturally explained by the addition of fluxes of stars of very different colours. We have attempted a photometric separation to determine the magnitudes and colours of each component. The resulting magnitudes and colours for the primaries and secondaries are given in Table 3. The primary red giants of H110, 118 and 151 appear to be located in the clump and that of H107 on the early AGB.

Table 2. Orbital elements of the four spectroscopic binaries

Element	H107	H110	H118	H151
P [d]	806.5	74.055	155.78	1635.
	1.0	.020	.04	10.
T [HJD-2440000]	4781.4	5019.14	5197.6	5417.64
	3.3	.81	1.3	.21
e	0.485	0.000	0.131	0.868
	.006	.011	.007	0.002
γ [kms^{-1}]	50.46	50.42	50.48	50.58
	.10	.17	.11	.14
ω [°]	197.7		65.9	282.16
	1.2		2.9	.65
K [km s^{-1}]	19.25	32.17	24.45	20.07
	.17	.20	.17	.13
f(m) [M$_\odot$]	0.399	0.2560	0.2305	0.1681
	.016	.0049	.0056	.0083
a sini [Gm]	186.7	32.76	51.93	224.0
	2.6	.22	.43	4.6
$\sigma(O-C)$ [kms^{-1}]	0.50	0.78	0.52	0.52
n_{obs}	30	25	26	38
M_B^{min} [M$_\odot$]	1.88	1.49	1.42	1.25
M_B^{phot} [M$_\odot$]	1.7	1.5	1.4	1.4
$q = M_B/M_A$	0.79	0.71	0.68	0.59

Table 3. Photometric separation of the binaries

	Joined		Primary		Secondary	
No	V	B-V	V	B-V	V	B-V
107	11.63	1.06	11.84	1.31	13.54	0.33
110	12.77	0.89	12.95	1.07	14.83	0.23
118	12.95	0.93	13.14	1.11	15.02	0.27
151	12.86	0.97	13.01	1.12	15.10	0.29

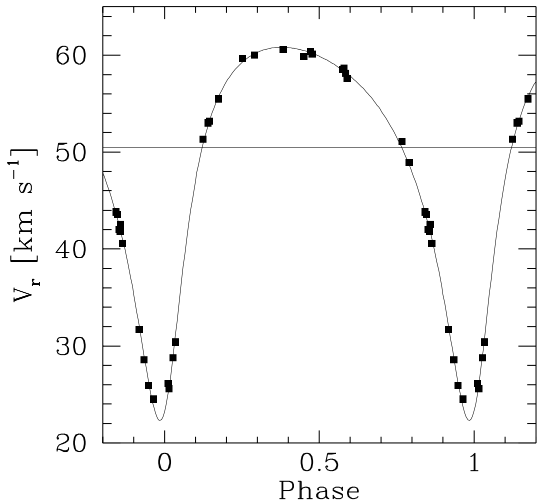

Fig. 2. Radial-velocity curve for H107.

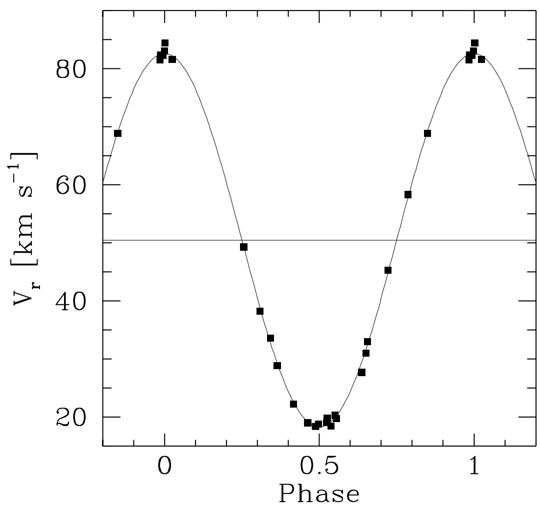

Fig. 3. Radial-velocity curve for H110.

The minimum and maximum masses from the spectroscopic elements and the photometric separation are quite similar, so the secondary masses are rather well constrained. The last row of Table 2 gives the corresponding mass ratio q.

3.4. The colour-magnitude diagram

The photographic data from Hassan (1976) have been corrected for the large systematic differences found between his data and ours, and all stars have been plotted in the colour-magnitude diagram (Fig. 6). An isochrone computed from the models of Bertelli et al. (1994) for log t = 9.00 and Z = 0.008 (corresponding to [Fe/H] = -0.40, close to the observed value [Fe/H] = -0.57, by Geisler et al. 1992), has been added. The best fit is obtained for $m - M$ = 12.45 and the observed $E(B-V)$ = 0.10. These values are close to those obtained by Pound & Janes (1986): 12.20 and 0.10 respectively. In spite of the scatter in the main-sequence region due to the use of photographic data, the agreement appears quite good. The isochrones even fit the location of the "single" red giant members rather well (large filled dots).

However, a closer look at the red giant region (Fig. 7) reveals that the giant clump is not at the place it is expected: most stars should fall on the bottom and left branch of the loop, while they are on the "wrong" side. However, with the present models it is impossible to produce a fit where the giants fall on the left side of the loop while the isochrone still fits the early AGB giants. Given the limited accuracy of the photographic photometry which defines the main sequence, the lack of direct reddening and metallicity determinations for the cluster as a whole and of membership data in the main-sequence region, it does not appear worthwhile at the moment to pursue the comparison further.

4. Conclusion

Our new UBV photometry and systematic radial-velocity survey of 24 giant stars in the field of Mel 71 has allowed us to

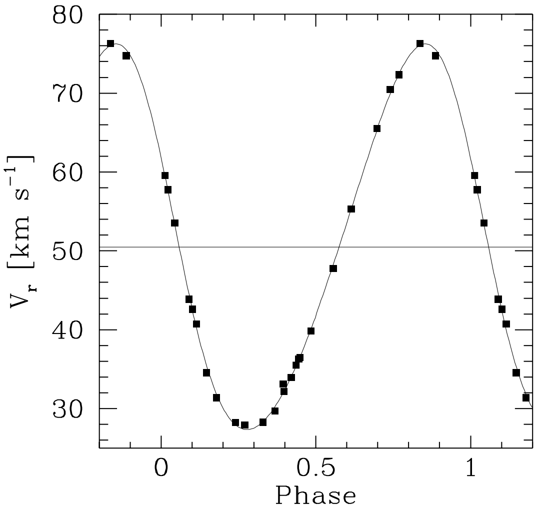

Fig. 4. Radial-velocity curve for H118

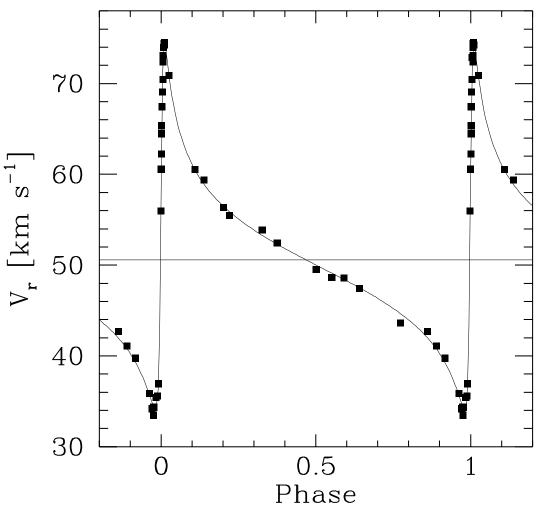

Fig. 5. Radial-velocity curve for H151

determine the membership of red giants in Mel 71 and to compute the mean cluster velocity (+50.14 ± 0.14 km s^{-1}). Eight spectroscopic binaries have been discovered and the binary frequency is unusually high: 50% (8/16). Four orbits have been determined.

Although the overall agreement of the theoretical isochrone fit on the observed colour-magnitude diagram of Mel 71 seems satisfactory given the accuracy of the photometric data, a detailed comparison reveals that the position of the clump is not where it is expected to be, i.e. where the models predict the maximum star density. This conclusion does not depend on the exact position and overall fit of the isochrone, also in the main-sequence region, because the comparison is made differentially between the giants on the ascending and asymptotic giant branches.

With the present models, it is difficult to obtain a better fit. It would be important to obtain well-calibrated and accurate CCD observations of several clusters of similar ages in order to compare observations and theory on the basis of several well-populated colour-magnitude diagrams. The membership information and binary detection resulting from this long-term program will be crucial input to the analysis of the observed red giant locus.

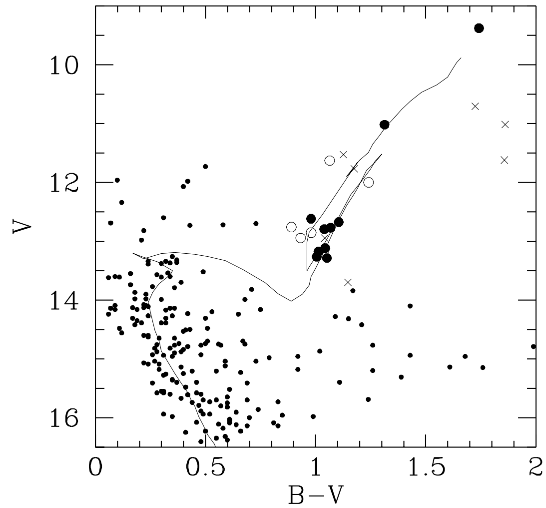

Fig. 6. Colour-magnitude diagram for Mel 71. The isochrone is from Bertelli et al. (1994) for logt = 9.00 and Z = 0.008, adjusted for the observed reddening. Large black dots: red giant members, large open circles: spectroscopic binaries, crosses: non-members, small dots: photographic data.

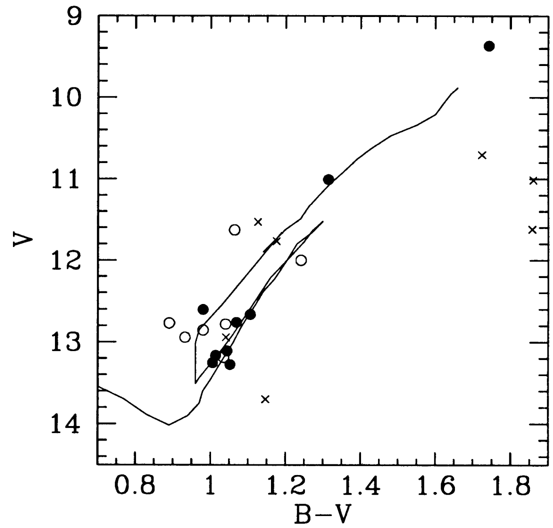

Fig. 7. Closeup of the red-giant region of the colour-magnitude diagram of Mel 71, with the same isochrone as above.

Acknowledgements. We are grateful to Drs Bo Reipurth and Catherine Turon who contributed some critical observations of H151 during phases of rapid variation in February 1992. The work of JCM and MM has been supported by continuous grants from the Swiss National Foundation for Scientific Research (FNRS), while JA thanks the Danish Natural Science Research Council, the Carlsberg Foundation, and the Danish Board for Astronomical Research for support of this research.

JJC gratefully acknowledges financial support through the Argentine institutions Fundación Antorchas and CONICOR.

References

Baranne A., Mayor M., Poncet J.-L. 1979, Vistas in Astron. 23, 279
Bertelli G., Bressan A., Chiosi C., Fagotto F., Nasi E. 1994, A&AS 106, 275
Cousins A.W.J. 1973. Mem. RAS 77, 223
Cousins A.W.J. 1974, MNASSA 33, 149
Geisler D., Clariá J.J., Minniti D. 1992, AJ 104, 1892
Graham J.A. 1982, PASP 92, 244
Hassan S.M. 1976, A&AS 26, 9
Mayor M., Maurice E. 1985, In: IAU Coll. 88, eds A.G.D. Philip, & D.W. Latham, L. Davis Press, (Schenectady, N.Y.), p. 35
Mermilliod J.-C., Mayor M. 1990, A&A 237, 61 (paper III)
Mermilliod J.-C., Mayor M. 1992, in "Binaries as Tracers of Stellar Formation", Eds. A. Duquennoy & M. Mayor (Cambridge, Cambridge University Press), p. 183
Mermilliod J.-C., Mayor M. 1996, in "Cool Stars, Stellar Systems and the Sun" ASP Conf. Ser. (in press), Eds R. Pallavicini & A.K. Dupree
Pound M.W., Janes K.A. 1986, PASP 98, 210

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.